Pointers, References & Iterators

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Content

- Pointers and references
- *auto* specifier
- *const* Qualifier
- Iterators

Pointers and references

- A reference is not an object. Hence, we may not have a pointer to a reference

A reference to `const` may refer to an object that is not `const`

- A reference to const restricts only what we can do through that reference
- Binding a reference to const to an object says nothing about whether the underlying object itself is const
- Because the underlying object might be non const, it might be changed by other means

```
int i = 42;
int &r1=i;           // r1 bound to i
const int &r2 = i;   // r2 also bound to i; but cannot be used to
                     // change i
r1=0;                // r1 is not const; i is now 0
r2 = 0;              // error: r2 is a reference to const
```


!! References cannot be stored in a vector

```
std::vector<int> hello; //  OK
std::vector<int &> hello; // Error! Pointer to reference is
                          // illegal!
```

- Containers values **must be *Assignable***
- References are *non-assignable* (you can only initialize them once when they are declared, and you cannot make them reference something else later)
- Other non-assignable types are also not allowed as components of containers, e.g. vector<const int> is not allowed

!! This is illegal because once we define a reference:
int &r1 = i;
we cannot change it!
This means that we cannot store references in containers that allows the assignment.
With vectors we can do:
v1 = v2;
and v1 becomes a copy of v2.
We cannot accept it because references DO NOT CHANGE.

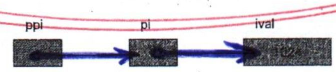
Pointers to Pointers

- There are no limits to how many type modifiers can be applied to a declarator
- When there is more than one modifier, they combine in ways that are logical but not always obvious
- A pointer is an object in memory, so like any object it has an address. Therefore, we can store the address of a pointer in another pointer
- We indicate each pointer level by its own *. That is:
  - we write ** for a pointer to a pointer
  - *** for a pointer to a pointer to a pointer, and so on

Pointers to Pointers

!!

```
int ival = 1024;
int *pi = &ival;   // pi points to an int
int **ppi = &pi;   // ppi points to a pointer to an int
```




```
cout << "The value of ival\n"
<< "direct value: " << ival << "\n" << "indirect
value: " << *pi << "\n" << "doubly indirect value: "
<< **ppi << endl;
```

A real example of something we need MPI!!
- **MPI_Init(int* argc, char*** argv)**

`auto` Specifier

The `auto` type specifier

- It is not uncommon to want to store the value of an expression in a variable
  - To declare the variable, we have to know the type of that expression
- Under C++ 11, we can let the compiler figure out the type for us by using the **auto** type specifier
- Unlike type specifiers, such as double, that name a specific type, auto tells the compiler to deduce the type from the initializer
  - A variable that uses auto as its type specifier **must** have an initializer

Notice that we can use "auto" only if we're performing an assignment

The `auto` type specifier

```
// the type of item is deduced from the type of the result of
// adding val1 and val2
auto item = val1 + val2; // item initialized to the
                         // result of val1 + val2
```

For example:
auto item;
is **not** enough

Traversing a vector

```
vector<int> v{1,2,3,4,5,6,7,8,9};

for (auto &i : v) // for each element in v (note: i is a
                  // reference)
    i *= i; // square the element value

for (auto i : v) // for each element in v
    cout << i << " "; // print the element

cout << endl;
```

Here **i** is a reference to the elements in **v**, which means that we're squaring **v** (not a copy)

Instead here **i** is a copy of the elements in **v**

Useful use of references

- A range-for loop (assume v is a vector of strings):
  - `for (string s : v) cout << s << "\n";` // s is a copy of all v[i]
  - `for (string& s : v) cout << s << "\n";` // no copy
  - `for (const string& s : v) cout << s << "\n";` // and we don't modify v

!

Same thing for higher dimensional arrays

Range-for for accessing multiple dimensional arrays

```
int ia[3][4]; // array of size 3; each element is an array of
              // ints of size 4

size_t cnt = 0;
for (auto &row : ia) // for every element in the outer array
    for (auto &col : row) { // for every element in the inner array
        col = cnt; // give this element the next value
        ++cnt; // increment cnt
    }
```


Iterators

Iterators

– we use iterators as pointers

- We can use subscripts to access the characters of a string or the elements in a vector
- There is a more general mechanism — **iterators** — that we can use for the same purpose
- The library defines **several** other kinds of **containers.** All of the library containers have **iterators**, but only a **few** of them **support** the **subscript operator**
- You can think to an **iterator as a pointer to access any container**
- **If we use iterators instead of subscripts, we can change easily the container type without changing our code**
- Like pointers, iterators give us **indirect access** to an object
  - An iterator can be used to fetch an element
  - Iterators have also operations to move from one element to another
  - An iterator may be valid or invalid

Using Iterators

- Unlike pointers, we do not use the address-of operator to obtain an iterator
- Instead, types that have iterators have members that return iterators: **begin()** and **end()**
  - The begin member returns an iterator that denotes the first element, if there is one
  - The iterator returned by end is an iterator positioned "one past the end" of the associated container (or string)

Using Iterators

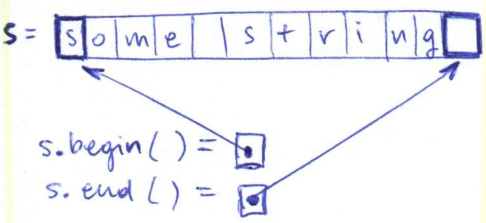
```
// the compiler determines the type of b and e
// b denotes the first element and e denotes one past the
// last element in v
auto b = v.begin(), e = v.end(); // b and e have the same
                                 // type
```

!

(here v is a vector)
but can actually be any container

- If the container is empty, the iterators returned by begin and end are equal, they are both off-the-end iterators

!!!



Using Iterators

!!!

```
string s("some string");

if (s.begin() != s.end()) { // make sure s is not empty
        auto it = s.begin(); // it denotes the first character in s
        *it = toupper(*it); // make that character uppercase
}

// process characters in s until we run out of characters or
// we hit a whitespace
for (auto it = s.begin(); it != s.end() && !isspace(*it); ++it)
        *it = toupper(*it); // capitalize the current character
```

Means go to the next element

Important use != instead of <
If we change the type it might not work

every time we access a data structure we have to check if the data structure is empty

*it is the first element of the string (so it's a character) while it is a pointer to it

after this instruction we'll get: "Some string"

after this we get: "SOME string" (because we go on until we meet a space)

Standard container iterator operations

*iter	Returns a reference to the element denoted by the iterator *iter*
iter->memb (*iter).memb	Dereferences *iter* and fetches the member *memb* from the underlying element
++iter	Increments *iter* to refer to the next element in the container
--iter	Decrements *iter* to refer to the previous element in the container
iter1==iter2 iter1!=iter2	Compares two iterators. Two iterators are equal if they denote the same element or if they are the **off-the-end** iterator for the **same container**

we access to the element

to access to a member in a class

we move →

we move ←

same element or both the one past of the end of the same container!

If iter1 is pointing at the one past the end of a container 1 (e.g. "vector1") and iter2 is pointing at the one past the end of a container 2 (e.g. "vector 2") then iter1 ≠ iter2

! Operations supported by vector and string iterators

(Only by vector and strings! Be careful!!)

iter + n iter - n	Adding (subctracting) an integral value *n* from the iterator *iter* yields an iterator *n* elements forward of backward than *iter* within the container
iter1 +=n iter1 -=n	Assign to *iter1* the value of adding (subctrating) n to *iter1*
iter1-iter2	Compute the number of elements between *iter1* and *iter2*
>,>=,<,<=	One iterator is less than another if it denotes an element that appears in the container before the one referred to

here we don't change the iterators

here we change the iterators

Iterator types

- The library types that have iterators define types named `iterator` and `const_iterator` that represent actual iterator types

```
vector<int>::iterator it; // it can read and write vector<int>
                          // elements
string::iterator it2; // it2 can read and write characters in a
                      // string
vector<int>::const_iterator it3; // it3 can read but not write
                                 // elements
string::const_iterator it4; // it4 can read but not write
                            // characters
```

type:: iterator it; read and write
type:: const_iterator it; Only read

However it better to do:
auto it = v.begin();
in this way "it" adapts always to what v becomes

The cbegin and cend operations

!

```
vector<int> v;
const vector<int> cv;
auto it1 = v.begin(); // it1 has type vector<int>::iterator
auto it2 = cv.begin(); // it2 has type vector<int>::const_iterator
```

non constant
constant

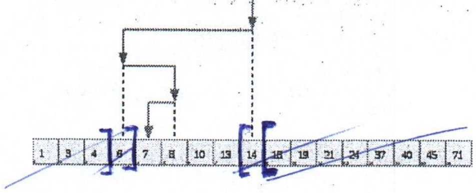
- It is usually best to use a const type (such as const_iterator) when we need to read but do not need to write to an object
- To let us ask specifically for the const_iterator type, the C++ 11 introduced two new functions named cbegin and cend

!!!

```
auto it3 = v.cbegin(); // it3 has type vector<int>::const_iterator
```


Binary Search

- Sorted arrays
- Looking for 7
- What happens if you are looking for 5?



Arithmetic operations on iterators – Binary search

```
vector <string> text
// intitialize text
// text must be sorted
sort(text.begin(), text.end());
// beg and end will denote the range we're searching
auto beg = text.cbegin(), end = text.cend();
auto mid = text.cbegin() + (end - beg)/2; // original midpoint
s=....
// while there are still elements to look at and we haven't yet // found s
while (mid != end && *mid != s) {

        if (s < *mid) // is the ele   we want in the first half?
                end = mid; // if so,   range to ignore the
                        // second half
        else // the element we want is in the second half
                beg = mid + 1; //start looking with the ele
        mid = beg + (end - beg)/2; // new midpoint
}
 if (mid!= text.end() && s == *mid)
                cout <<"Yes I found "<<s<<" in text"<<endl;
        else
                cout <<"Sorry I cannot find "<<s<<" in text"<<endl;
```

Complexity ?

O(log(n))

Here we rely on [redacted], no other way to write this while (if-else below) correctly

&& short-circuit

DEMO

Arithmetic operations on iterators – Binary search

```
vector <string> text
// intitialize text
// text must be sorted
sort(text.begin(), text.end());
// beg and end will denote the range we're searching
auto beg = text.cbegin(), end = text.cend();
auto mid = text.cbegin() + (end - beg)/2; // original midpoint
s=....
// while there are still elements to look at and we haven't yet // found s
while (mid != end && *mid != s) {

        if (s < *mid) // is the element we want in the first half?
                end = mid; // if so, adjust the range to ignore the
                        // second half
        else // the element we want is in the second half
                beg = mid + 1; //start looking with the element just after mid
        mid = beg + (end - beg)/2; // new midpoint
}
 if (mid!= text.end() && s == *mid)
                cout <<"Yes I found "<<s<<" in text"<<endl;
        else
                cout <<"Sorry I cannot find "<<s<<" in text"<<endl;
```

end-beg = # elements in the vector

DEMO

first we ask if mid is a valid iterator

References

- Lippman Chapters 2 and 3

Advanced readings

Pointers and references

- A reference is not an object. Hence, we may not have a pointer to a reference
- However, because a pointer is an object, we can define a reference to a pointer

```
int i = 42;
int *p;         //p is a pointer to int
int *&r = p;    // r is a reference to the pointer p
r = &i;         // r refers to a pointer; assigning &i to r makes
                //p point to i
*r = 0;         // dereferencing r yields i, the object to which p points;
                // changes i to 0
```


Pointers and Arrays

- In C++ pointers and arrays are closely intertwined. In particular, when we use an array the compiler ordinarily converts the array to a pointer
  - in most places when we use an array, the compiler automatically substitutes a pointer to the first element

```
string nums[] = {"one", "two", "three"}; // array of strings
string *p = &nums[0]; // p points to the first element in nums

string *p2 = nums; // equivalent to p2 = &nums[0]
```


Pointers and Arrays

- There are various implications of the fact that operations on arrays are often really operations on pointers
  - When we use an array as an initializer for a variable defined using auto, the deduced type is a pointer, not an array

```
int ia[] = {0,1,2,3,4,5,6,7,8,9}; // ia is an array of ten ints
auto ia2(ia); // ia2 is an int* that points to the first element in ia
ia2 = 42; // error: ia2 is a pointer, and we can't assign an int to a
        // pointer
```

Pointers arithmetic

```
constexpr size_t sz = 5;
int arr[sz] = {1,2,3,4,5};
int *ip = arr; // equivalent to int *ip = &arr[0]
int *ip2 = ip + 4; // ip2 points to arr[4] (which is 5!), the last element in arr

// ok: arr is converted to a pointer to its first element; p points one
// past the end of arr
int *p = arr + sz; // use caution -- do not dereference!
int *p2 = arr + 10; // error: arr has only 5 elements; p2 has
                    // undefined value
```


Pointers arithmetic

- Although we can compute an off-the-end pointer, doing so is error-prone. To make it easier and safer to use pointers, C++ 11 library includes two functions, begin and end

```
int arr[] = {0,1,2,3,4,5,6,7,8,9};
int *beg = begin(arr); // beg points to the first element in arr

int *last = end(arr); // pointer just past the last element in arr
for (int *b = beg; b != last; ++b)
        cout << *b << endl; // print the elements in arr
```


Pointers arithmetic

- Subtracting two pointers gives us the distance between those pointers. The pointers must point to elements in the same array

```
auto n = end(arr) - begin(arr); // compute the number of
                                // elements in arr
```


Pointers arithmetic

- We can use the subscript operator on any pointer, as long as that pointer points to an element (or one past the last element) in an array

```
int ia[] = {0,1,2,3,4,5,6,7,8,9}; // ia is an array of ten ints
int *p = &ia[2];  // p points to the element indexed by 2
int j = p[1];     // p[1] is equivalent to *(p + 1),
                  // p[1] is the same element as ia[3]
int k = p[-2];    // p[-2] is the same element as ia[0]
```

- This last example points out an important **difference** between **arrays** and **library types** that have subscript operators
  - The **library types** force the index used with a subscript to be an **unsigned value**. The **built-in subscript** does **not**
  - The **index** used with the **built-in subscript** operator can be a **negative** value. Of course, the resulting address must point to an element in (or one past the end of) the array to which the original pointer points

Credits

- Bjarne Stroustrup. www.stroustrup.com/Programming